HANES

The design of a Walschaert valve gear to replace the Stephenson gear of a particular locomotive

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THE DESIGN OF A WALSCHAERT VALVE GEAR TO REPLACE THE STEPHENSON GEAR OF A PARTICULAR LOCOMOTIVE

BY

WILLIAM RAMBO HANES

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

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May 24, 1910

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

William Rambo Hanes

ENTITLED THE DESIGN OF A WALSCHAERT VALVE GEAR TO REPLACE THE STEPHENSON GEAR OF A PARTICULAR LOCOMOTIVE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Railway Engineering

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THE DESIGN OF A WALSCHAERT VALVE GEAR TO REPLACE THE STEPHENSON GEAR OF A PARTICULAR LOCOMOTIVE.

Introduction.

With the increase in the size and tractive power of locomotives, the available space between the frames has become quite limited. This makes it difficult to apply the common Stephenson type of valve motion, with its large parts and excessive inertia and heating effects, to many of the larger engines. It has therefore become desirable to make use of some form of valve gear for locomotives which can be applied outside the drivers and which will reduce the inertia and heating to a minimum. The Walschaert valve gear lends itself to these requirements admirably and hence has met with more and more favor among locomotive designers and builders. Today a great number of our locomotives are fitted with this gear and indications point to the future elimination of all other forms.

So great has been the favor with which this valve gear has met, that it is thought that in the future there may be some cases in which it will be found desirable to substitute it on existing engines for the heavier and more complicated Stephenson type. In such cases it will be found necessary to design a Walschaert valve gear to suit each particular case and it is the object of this thesis to design such a valve gear for the R-2 type of locomotive of the Chicago Burlington and Quincey Railroad.

Theory.

The theory of the Walschaert valve gear is very simple and in its discussion it is best to begin with a simple eccentric gear such as is used with a slide valve engine designed to run in one fixed direction. Referring to Fig. 1, AO is the crank of such an

engine and OB is the simple eccentric which is set at an angular advance of Θ degrees.

The motion given to a valve by the Walschaert gear may be divided into two distinct parts: that due to the main crank and crosshead, and that due to the eccentric. The eccentric is set at an angle of 90 degrees with the main crank and as is seen in Fig. 3 both it and the main crank are in effect cranks or eccentrics giving motion to the valve.

Referring to the simple eccentric (Fig. 1), suppose the single eccentric OB be replaced by its component eccentrics at 90 and 180 degrees respectively with AO. Let these components be OC and OD, neglecting the angularity of rods, the sum of the horizontal displacements of OC and OD with respect to O is identical with that due to the single eccentric OB. Thus the simple eccentric gear may be replaced by a gear of two eccentrics similar to the Walschaert.

This may be made clear by consideration of the Zeuner diagram shown as Fig. 2. When the crank is on dead center as shown, the components of OB; OC and OD, are as indicated. It is plain that the component OC does not give the valve any displacement from its mid-position when the crank is on the dead centres. It is also plain that on the centres the component OD exerts its maximum effect on the valve and gives it a displacement from the central position which is equal to the sum of the lap and lead. But this is precisely what the two motions of the Walschaert valve gear do. The common form of the Walschaert gear is shown by Fig. 3. OC is the eccentric 90 degrees ahead of the crank and by the combination lever EFG, the crank OA has its effect reduced in the proper ratio and reversed through an angle of 180 degrees thus becoming the 180° component. By placing the fulcrum of EFG at F, which is the end of

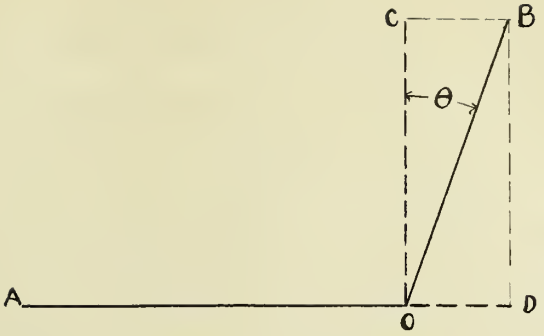


Fig. 1

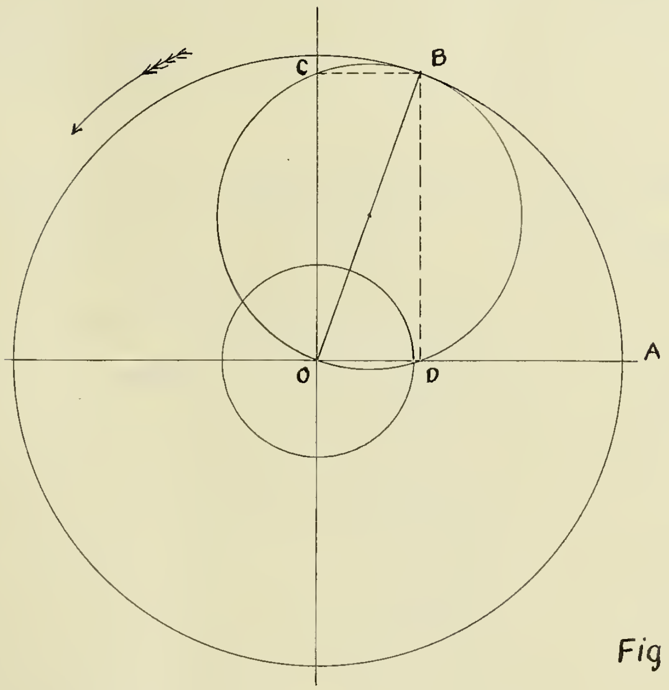


Fig. 2

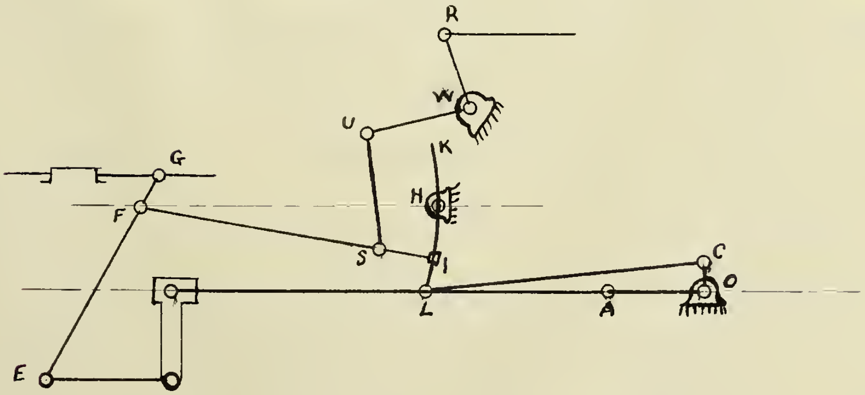


Fig. 3

the 90 degree component system, the effects of both the 90 and 180 degree component systems are correctly added or combined. The throw of OC, corrected for the lever ratios at the link, is identical with the OC component of the simple eccentric OB and the throw, OA, of the main crank reduced in the proper proportion and reversed as above mentioned is identical with OD, or the lap plus lead component. Thus it is seen that the underlying principle of the action of the Walschaert valve gear is simple and lies in the replacing of the eccentric of the simple engine gear by its 90 and 180 degree components.

The reversing and variation of cut-off feature of the Walschaert valve gear is shown in Fig. 3. The slotted link IK is pivoted at H and is given the proper motion by the eccentric strap CL. The end I of the radius rod IF is fastened to the link block and hence by shifting the position of the link block through the bellcrank UWR, the OC or 90 degree component of the motion may be varied from OC, 90 degrees ahead of OA, to zero and to OC^1 270 degrees ahead of OA. When I is at H, OC becomes zero and the valve is actuated only by the 180 degree or OD component. In this case the maximum part opening is equal to the lead and comes on the centres. When OC becomes a maximum 270 degrees ahead of OA, the resultant of it and OD is the equivalent eccentric OB^1 as seen by Fig. 4. This is seen to cause rotation in a counter-clockwise direction or in the opposite direction to that assumed in Fig. 1. When the value of OC is not a maximum or zero but is between the two, the resultant when it is combined with OD is somewhere between the values of OB or OB^1 and OD. Fig. 5 is a Zeuner diagram for a Walschaert valve gear and shows this fact quite plainly. OB is the equivalent eccentric when

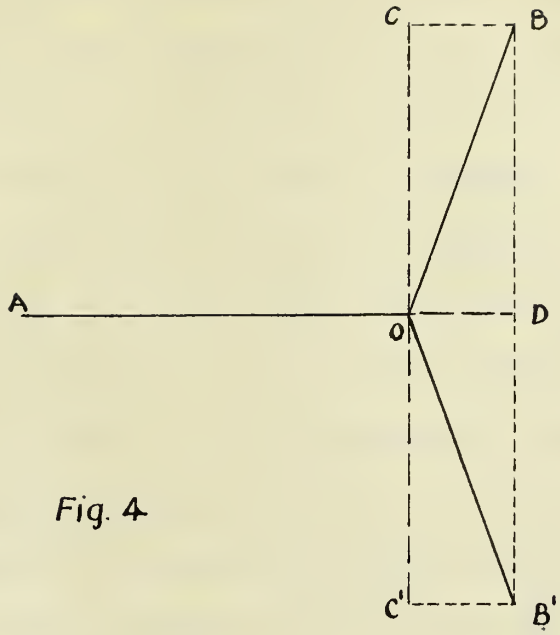


Fig. 4

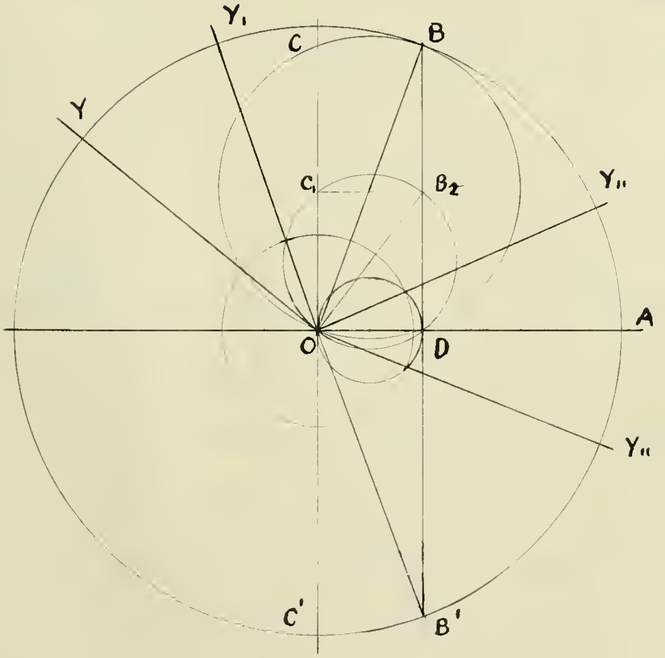


Fig. 5

OC is a maximum, and its circle, as is seen, determines cut-off at the position of the crank represented by OY. OB_2 is the equivalent eccentric when OC has the value OC_1 and its circle determines cut-off at the crank position OY_1. When OC is zero, OD is the resultant or equivalent eccentric and its circle determines the cut-off at the two positions OY_{11} or in other words, the gear is in a neutral position and rotation will not occur in either direction. Thus it is seem that through the link of the Walschaert valve gear, the direction of rotation is reversed and the cut-off is varied. The nearer zero OC is made the shorter the cut-off becomes and changing the position of the link block from one side of H to the other causes a reversal in the direction of rotation.

General Conditions Controlling The Design.

Having discussed the theory of the Walschaert valve gear, the general conditions controlling the particular design in hand will now be given attention.

As mentioned in the introduction, the locomotive for which the valve gear is to be designed is the R-2 type of the Chicago, Burlington, and Quincey Railroad. The drawings of that locomotive are at hand and they determine the conditions controlling the design. These conditions are best explained by proceeding with the method of laying out the valve gear.

The laying out of the valve gear may be divided or differentiated into the following steps:

1. Choose as reference lines (Plate 1.) the face of the rear flange and the center line of the cylinder.

2. Draw in the center line of the valve and its stem and

draw the line representing the plane of axle axes.

3. Locate the axle centers and draw in the wheel circles and the crank circles.

4. Draw in parts which may interfere with the valve gear such as guide bars and yoke and consider space that must be kept clear for crosshead, drivers, and side rods.

5. Take note of any peculiarities of the locomotive which will require special features in the design.

6. Knowing the required total travel of the valve and the value of the lap and lead, construct a Zeuner diagram and find graphically the 90° component eccentric or the maximum travel of the front end of the radius rod from its mid-gear position.

7. Knowing the lap and lead and the stroke of the piston, decide upon the exact location, proportion, and length of the combination lever and its link.

8. Decide upon the exact length, position, and essential proportions of the radius rod, its hanger and bellcrank, the link, the eccentric rod and the overhung eccentric.

These steps have been followed in the case of the particular problem under consideration. Steps one to four inclusive are such that no comment is necessary as reference to Plate 1 will show. In connection with step five, it is seen from the general assembly drawing and Plate 1 that the center line of the valve and its stem is between the vertical plane which contains the center line of the cylinder and the outside of the frames. This gives rise to an excessive offset in the valve gear as the parts must be so arranged that the motion is taken from the overhung eccentric and transmitted to the valve stem. It also makes it necessary to place the combi-

nation lever between the crosshead guides and the front driver. Most locomotives, which are fitted with the Walschaert valve gear have the center line of the valve stem outside the vertical plane of the cylinder centerline and very nearly in line with the overhung eccentric. In the design worked out in this thesis, the ordinary link trunnions are replaced with substantial journals. The outside journal is made slightly larger than the inside one and carries a crank on its outer end. This crank is connected at its end to the end of the eccentric rod and through it the link is given its oscillating motion. Thus part of the offset is eliminated. The remainder of this offset is overcome by curving the radius rod. It is also seen that in placing the link close to the drivers, its height must be excessive in order to avoid interference with the connecting rod. With this point in view, the connection of the combination lever with the radius rod is placed above its connection with the valve stem guide. Also, in order to carry out the design successfully, it becomes necessary to design new and special main crank pin, yoke, and upper guide bar.

Step six is worked out on Plate 2. The known total travel of the valve is 6 inches and the lap and lead are known to be 1 inch and 1/16 inch respectively. The sum of the lap and lead or 1 1/16 inch is equal to the length of the 180 degree component eccentric as explained under "Theory" and knowing this and the maximum valve travel, which is twice the length of the equivalent eccentric, a Zeuner diagram is drawn and the 90 degree component eccentric found. On Plate 2 this diagram is shown. A large scale is used for accuracy and the value of the 90 degree component is obtained by scaling the drawing.

In step seven, the proportionate lengths of the combination lever are determined. The ratio of the 180 degree component eccentric to one half the piston travel is $\frac{17}{192}$.

Hence $\frac{17}{192} = \frac{\text{distance between upper pins of lever}}{\text{distance between highest and lowest pins of lever.}}$

The distance between the upper pins is chosen as 4 inches and letting the total length of the combination lever between axes of end pins be represented by X, transposing, the equation becomes

$$X = \frac{192 \times 4}{17} = 45\ 1/8 \text{ inches.}$$

Referring to Plate 1, it is seen that a combination lever of these dimensions fits very nicely in the available space. The length of the link which actuates the combination lever is then chosen and the height of its connection with the crosshead is made such that it is horizontal at the ends of the stroke.

Having decided upon the proportions and location of the combination lever, step eight may be taken up. When the engine is on the center, the location of the upper pin, which connects the combination lever and the radius rod, may be found by placing the pin of the valve slide in its mid-position and drawing the combination lever in vertically. This is shown in Plate 1. The position of the upper pin when the combination lever is thus drawn is the desired one. The length of the radius rod is chosen so that the link may be located somewhat behind the guide yoke and so that the off-set mentioned in step five may be cared for. The arc of the link is drawn and its dimensions determined. The length of the lever which actuates the link, the throw of the overhung eccentric, and the length of the eccentric rod are then chosen. Next the

location and principle dimensions of the radius rod hanger and its bell crank are determined. Owing to lach of space, the bell crank is attached to the boiler and the angle between its arms and the position of its axis relative to the hanger made such that the tendency is for the hanger to remain perpendicular to the mid-position of the radius rod for different positions of the link block in the link when the locomotive is moving forward.

Discussion of The Finished Design.

It is perhaps best to begin the discussion of the finished design by considering the forces which are acting on the gear. These forces vary greatly from time to time and very little definite knowledge exists about them. They may be divided into three classes: friction forces; inertia forces; and accidental forces. The friction forces arise in the valve and its stem and in the various parts of the gear. The inertia forces of greatest importance occur in connection with the valve as the various parts of the gear are comparatively light and are so constructed and move in such directions that their inertia effects may be neglected. Moreover the inertia forces are constantly opposed and added to by the friction forces and, as has been shown by recent tests, only make themselves felt during acceleration or de-celeration of the valve. The principal accidental force is encountered when increasing the point of cut-off and travel of the valve as oil sometimes carbonizes on the valve seats at the ends of the travel. It is claimed that the ordinary slide valve will ride over these oil deposits until they are worn down. The valve of the engine for which this gear is designed is of the piston type and hence cannot thus partially avoid this force. All of these forces are constantly varying and, as mentioned previously,

very little definite knowledge exists regarding them.

In Henderson's "Locomotive Operation", are given the results of some experiments on valves which were conducted at Purdue University by a committee of the Master Mechanics Association. The engine used for these tests was about the size of the one dealt with in this thesis and when the valve yoke is considered, had a valve which is equivalent in weight to the one with which this design deals. The maximum force to move that valve was found at high speeds to be about 1200 pounds. With this in mind, 1500 pounds is considered as a very safe approximation for the force necessary to actuate the valve dealt with in this design. Referring to the stem of that valve it is seen to be a column about 12 inches long and 1 3/4 inches in diameter. Considering it to be made of steel and as a column with fixed ends, it follows according to Rankine's formula that the allowable force

$$P = aS/1 + \phi\left(\frac{l}{r}\right)^2.$$

$$\phi \text{ for ends fixed} = \frac{1}{25000}$$

$$\left(\frac{l}{r}\right)^2 = 138 \qquad a = 2.405$$

$$S = 60,000$$

substituting

$$P = \frac{2.405 \times 60,000}{1 + \frac{138}{25000}} = 143,600 \text{ lb.}$$

Thus the factor of safety proves to be in the case of the valve stem, 143,600/1500 or about 96. This factor of safety is rather absurd in so far as strength is concerned and shows how, in such

work as locomotive valve gears, standard practice is more dependent on other considerations of a practical nature such as pin sizes for wear than on theoretical calculations. Hence in the design of most of the various parts of the gear modern practice has been followed rather than attempting to base the size of parts on theoretical calculations. In most cases the sizes based on such calculations would be too small and only in the case of the long and slender radius rod has it seemed necessary to resort to them. Many emperical rules and formulas for parts of valve gears exist; but these seem to be more or less generalizations of standard practice and it has seemed more advisable to make a direct study of standard practice and proportion the parts accordingly.

The discussion proper of the finished design will now be taken up.

Combination Lever and its Actuating Link

These parts are shown on Plate 3. The pins are the most important feature and are made large so as to afford ample wearing surfaces and are case hardened. The other sections are made to go with them and as to proportions, conform to standard practice. The two upper pins of the combination lever are made with tapers so that wear may be easily taken up.

Valve Rod Guide and Upper Guide Bar.

Plate 4 shows these parts. They are made of cast steel. The valve rod guide and its rider are finished all over and the bushing for the combination lever pin is case hardened. The upper guide bar is the same as the one with which the locomotive was fitted with the exception of the lugs for carrying the valve guide.

Radius Rod and Guide Yoke.

These parts are grouped on Plate 5. The radius rod is about 56 inches long axially and is a case of a column with round ends. According to Rankine's formula

$$S = P/a\ (1 + \phi(\frac{l}{r})^2)$$

in this case

assume $S = 10,000$

$P = 1500$

for round ends $\phi = \frac{4}{25000}$

$l = 56$

assume $r = 0.62$ and $\frac{l}{r} = 90.5$

assuming the depth of the rod to be twice the width, $a = 8r^2$

substituting $60,000 = \frac{1500}{8r^2}\ (\ 1 + \frac{4 \times 81.80}{25})$

$$r^2 = \frac{1500}{8 \times 10,000}\ (1 + \frac{4 \times 81.80}{25}) = 0.2622$$

$r = .513$

This shows that the previous assumption of r as 0.62 is about correct and that in making the radius rod 1 1/4 inches wide and 2 1/2 inches deep to conform to standard practice it is perfectly safe in so far as strength is concerned. The bushing in the end of the radius rod is case hardened so as to prevent too rapid wear. The guide yoke differs from the old one only in the portion which projects beyond the frame. This difference is made necessary in order to carry the link supports.

The Link.

Plate 6. shows the link. Its parts are made of cast steel and are finished all over. As explained before, the link is actuated through its outside trunnion or journal. This case is very similar if not identical with the rocker of the old Stephenson gear which was fitted to the engine. Hence the diameter of the trunnions or journals are made about the same as the diameter of the rocker of the old gear.

The Link Supports and Actuating Lever.

The link supports and actuating lever are shown on Plate 7. The supports are of cast steel and are so nearly alike that the same pattern will do for casting both of them. Their boxes are lined with hard brass and may be adjusted to take up wear. The lever which actuates the link is also made of cast steel and is proportioned in accordance with the rocker arm of the old gear. Its eccentric rod end is fitted with a case hardened steel bushing.

Eccentric Rod and Overhung Eccentric.

Plate 8 shows these parts. The eccentric rod is proportioned in accordance with several of its kind which are used on similar locomotives built by the American Locomotive Works. The end connecting with the link lever has a case hardened steel pin and the other end is fitted with adjustable brasses. The overhung eccentric is fitted with an eccentric pin of suitable size to stand service without excessive wear. The core of this pin is cast with the arm and has a case hardened steel bushing forced over it which acts as the wearing surface.

Radius Rod Hanger and its Bell Crank.

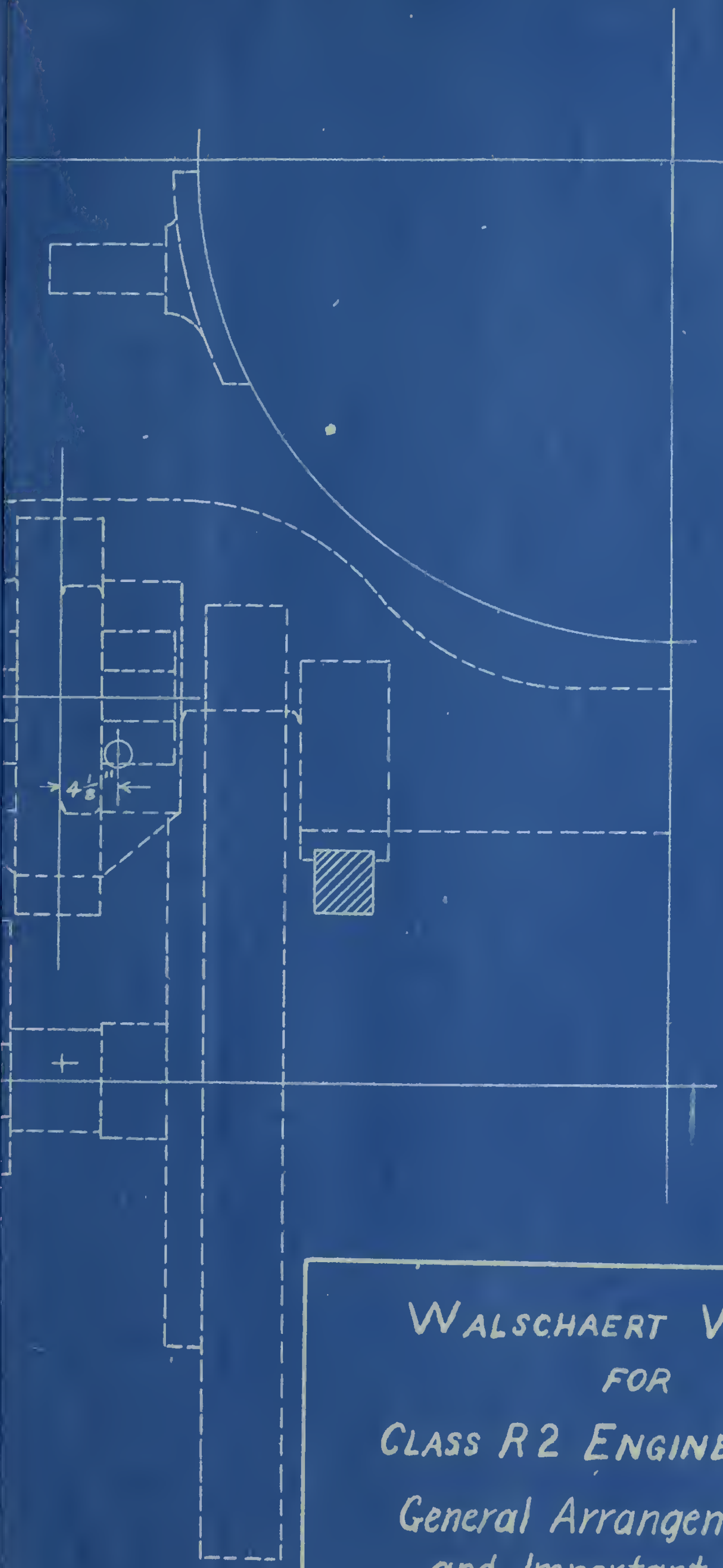
These parts are shown on Plate 9. The lower end of the hanger is fitted with a case hardened bushing. As mentioned before, the bell crank is located and proportioned so that the hanger tends to remain perpendicular to the radius rod for all mid positions of the valve.

Miscellaneous Parts such as Pins, Bolts,etc.

Plate 10 shows small parts which it did not seem advisable to show along with the larger pieces.

General assembly drawing.

Plate 11 is a general assembly drawing and shows the general arrangement of the completed gear in position on the engine.

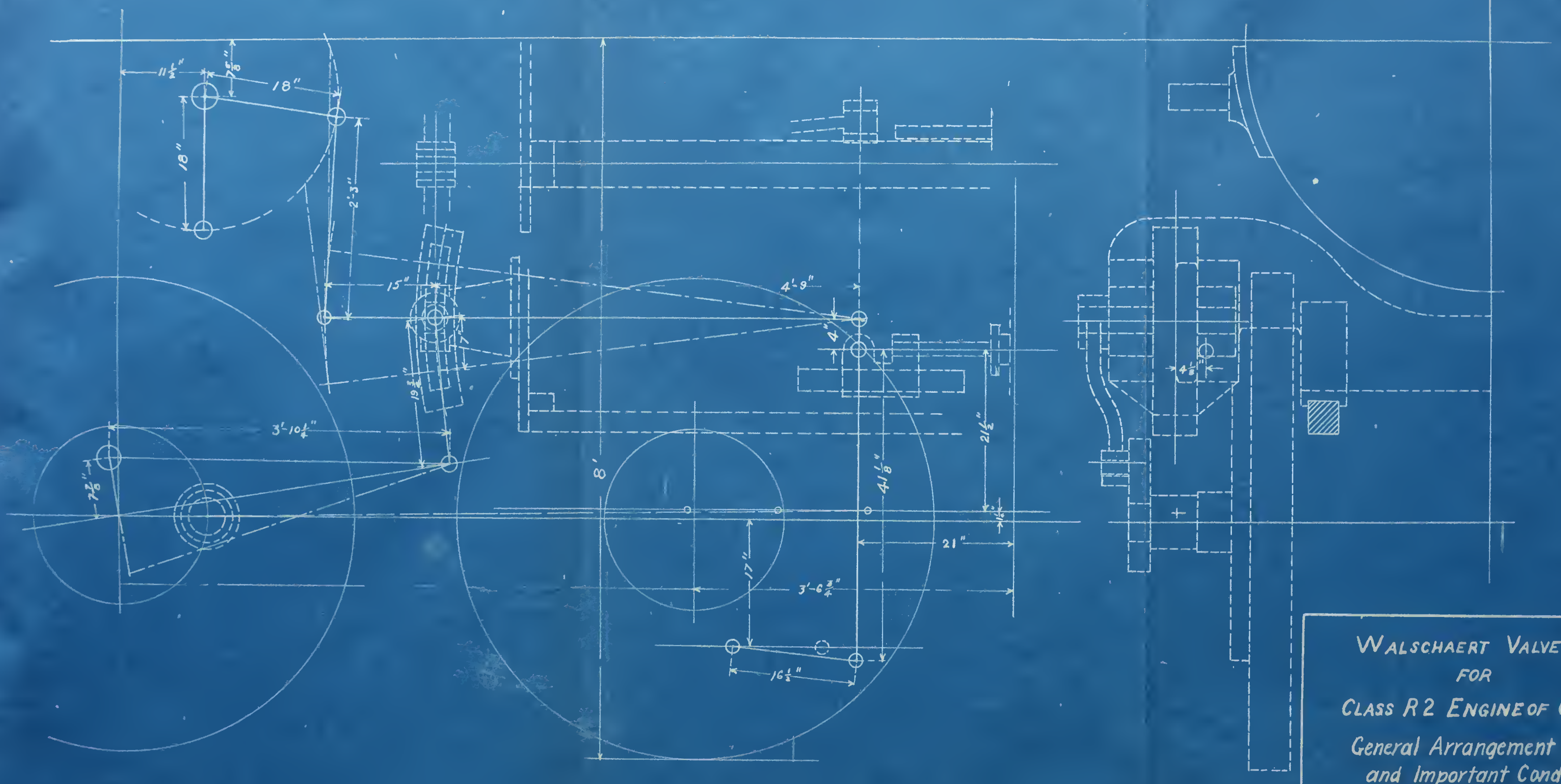


WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.&Q. R.R.

General Arrangement of Gear
and Important Conditions

Scale: 12" = 1'

PLATE I.

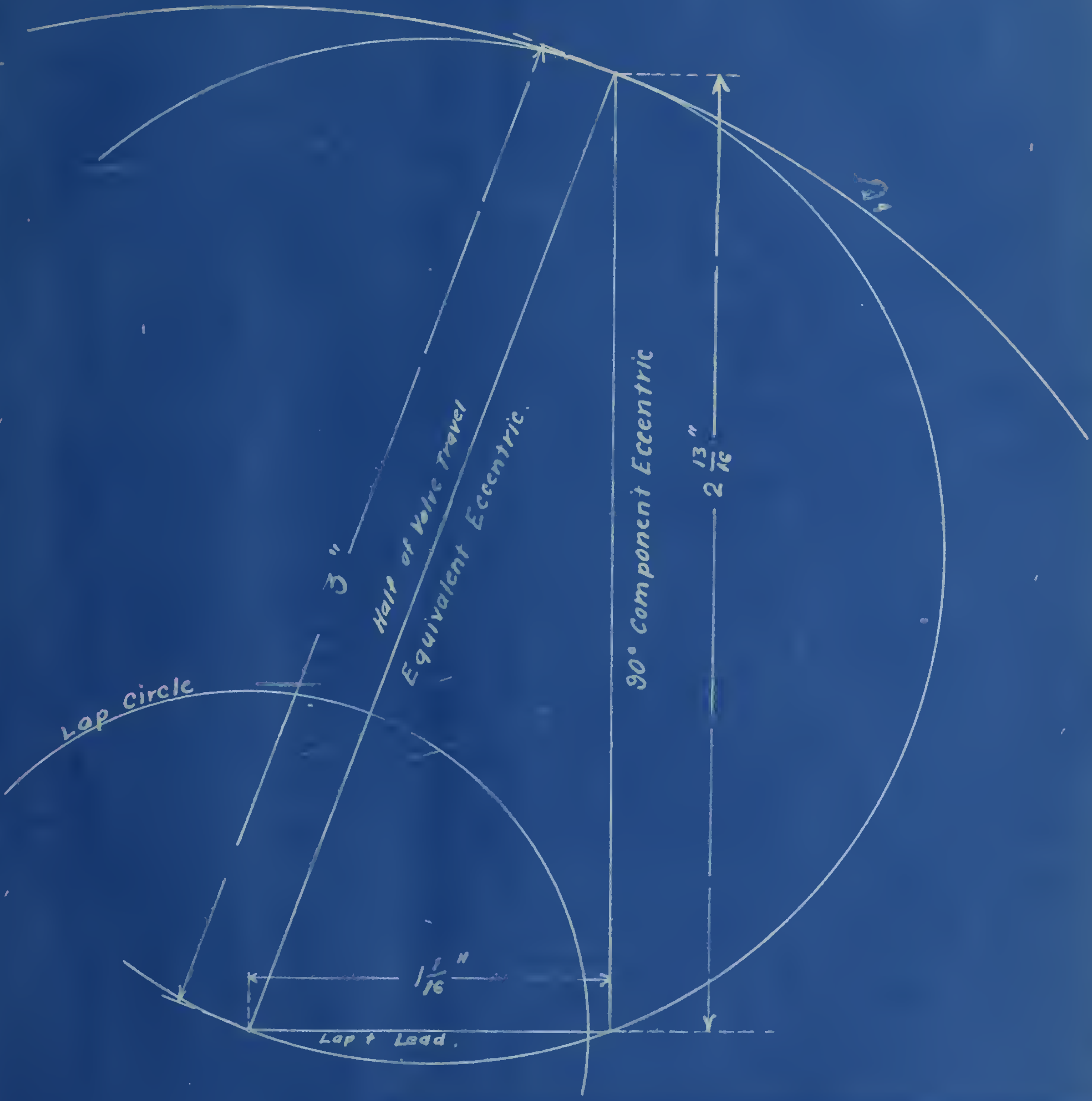


WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.&Q. R.R.

General Arrangement of Gear
and Important Conditions.

Scale: 1½" = 1'

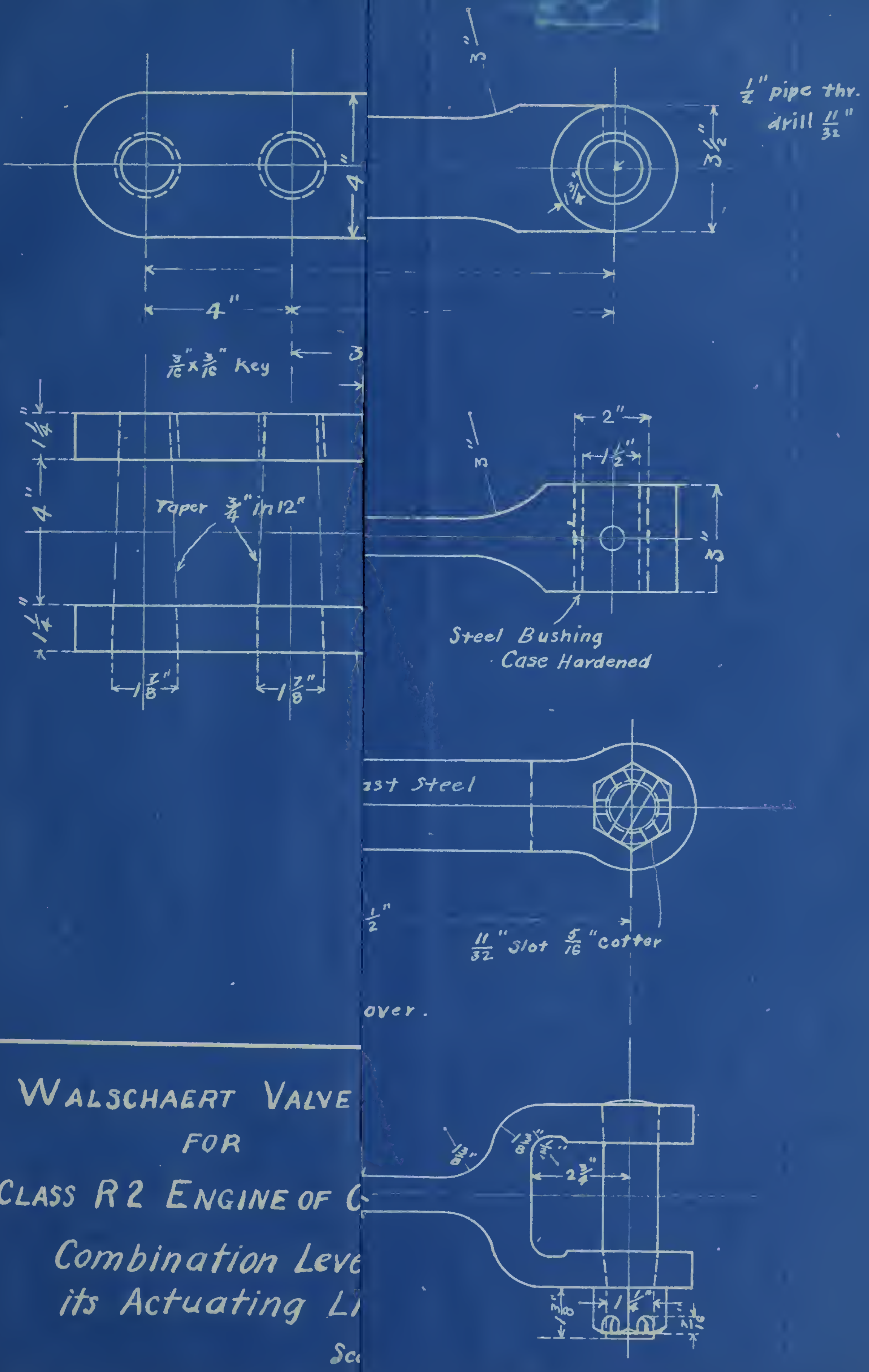
PLATE 2.



WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.+Q. R.R.

Zeuner Diagram for finding
90° Component Eccentric

Scale : 2" = 1"



WALSCHAERT VALVE

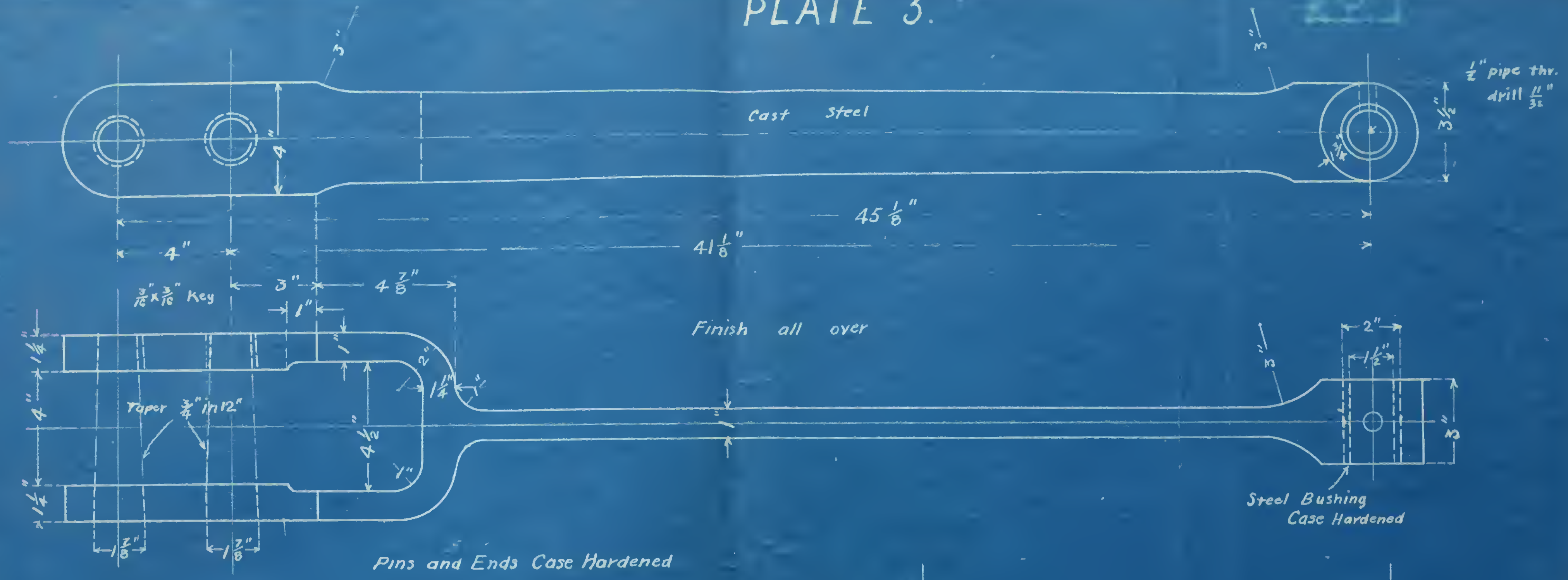
FOR

CLASS R2 ENGINE OF C

Combination Leve
its Actuating LI

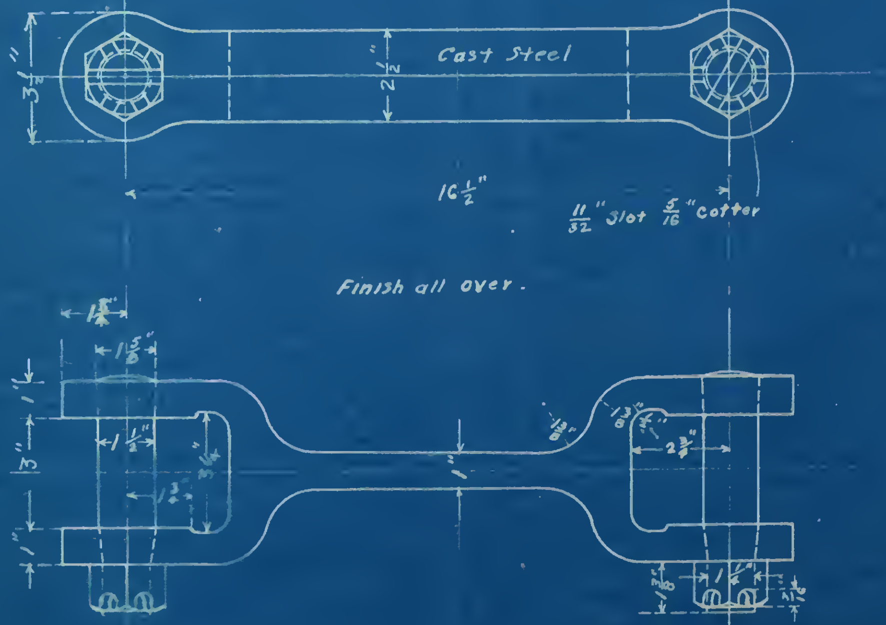
Sc

PLATE 3.



Finish all over

Pins and Ends Case Hardened



Finish all over.

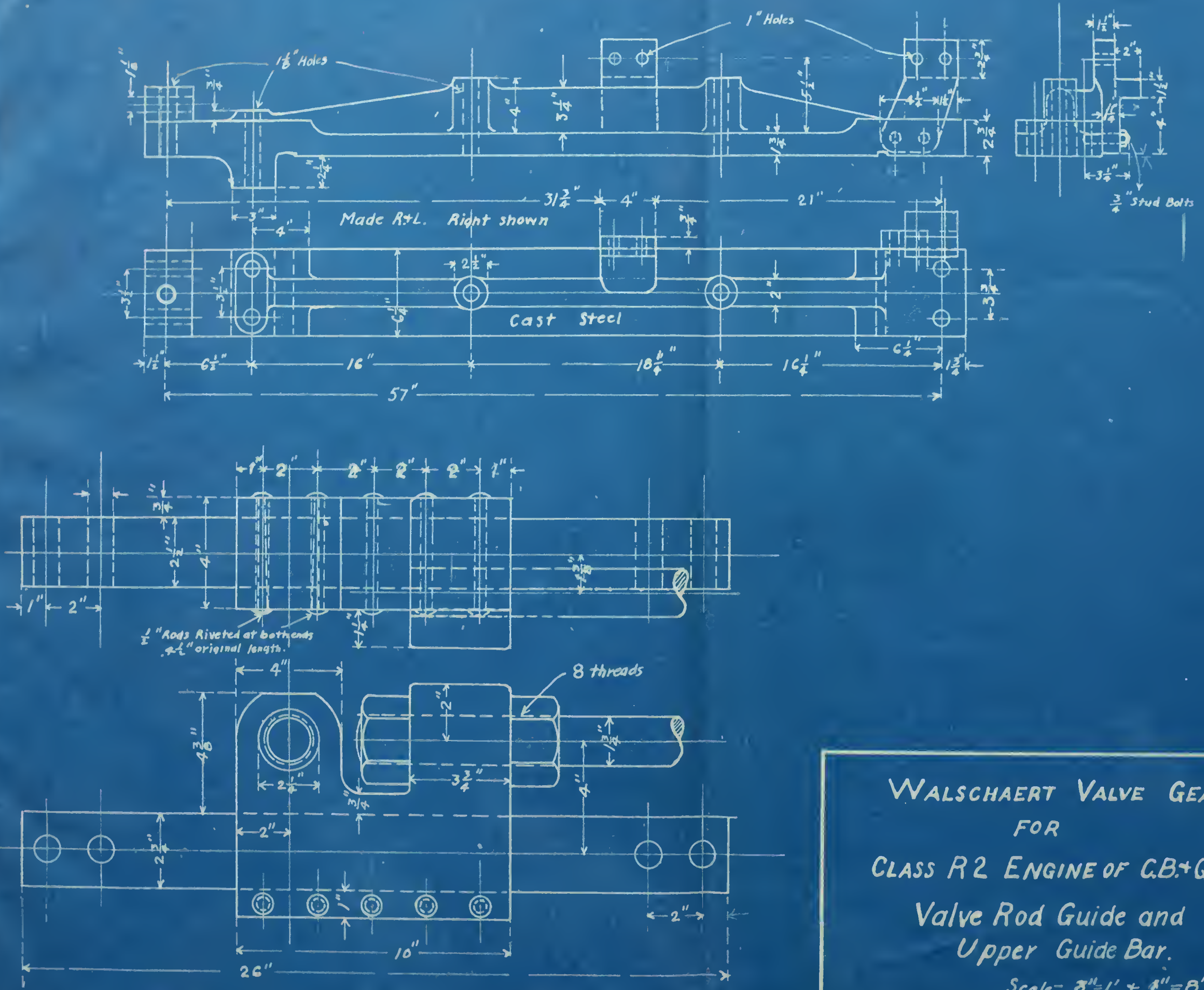
WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q.R.R.

Combination Lever and
its Actuating Link.

Scale: 3" = 1'

1"

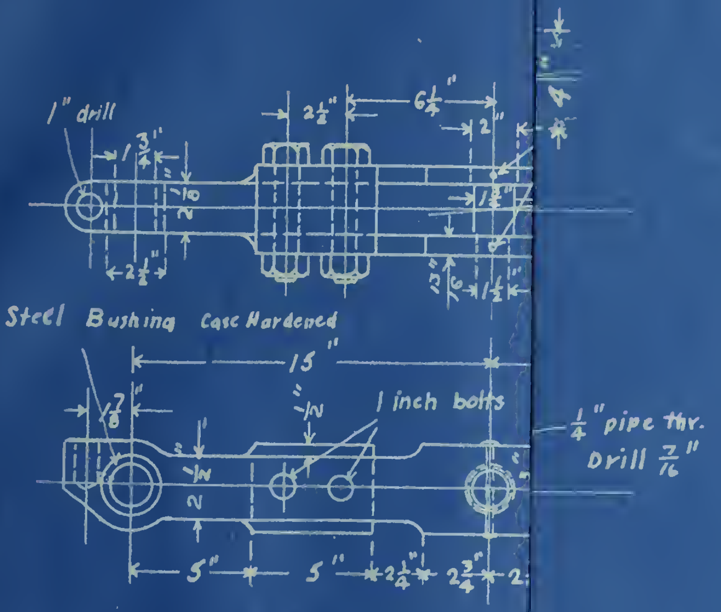
PLATE 4.

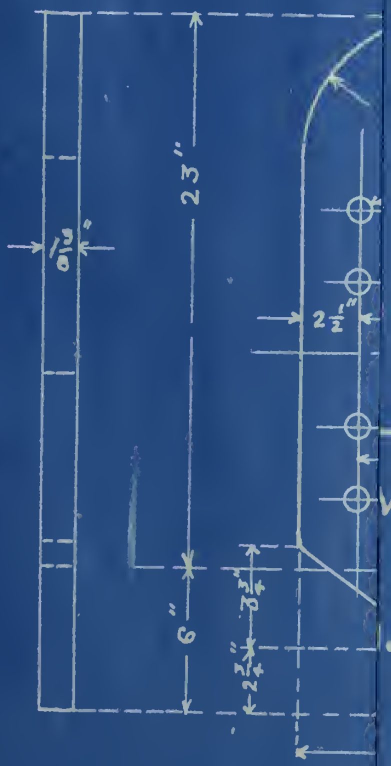


WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q.R.R.

Valve Rod Guide and
Upper Guide Bar.

Scale: 3"=1' + 1"=8"



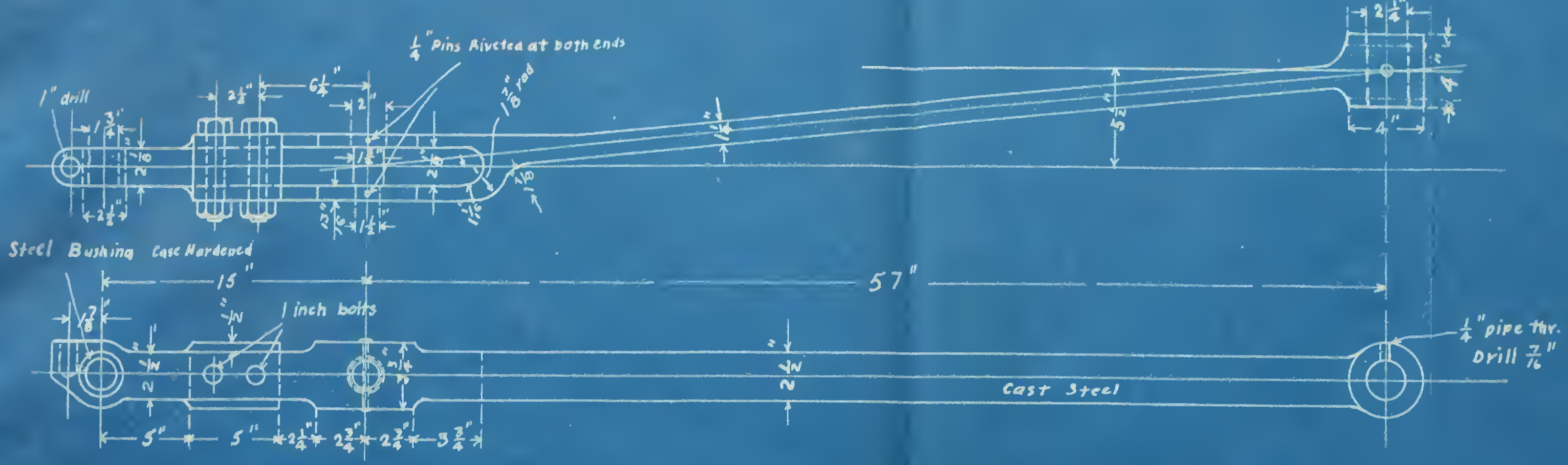


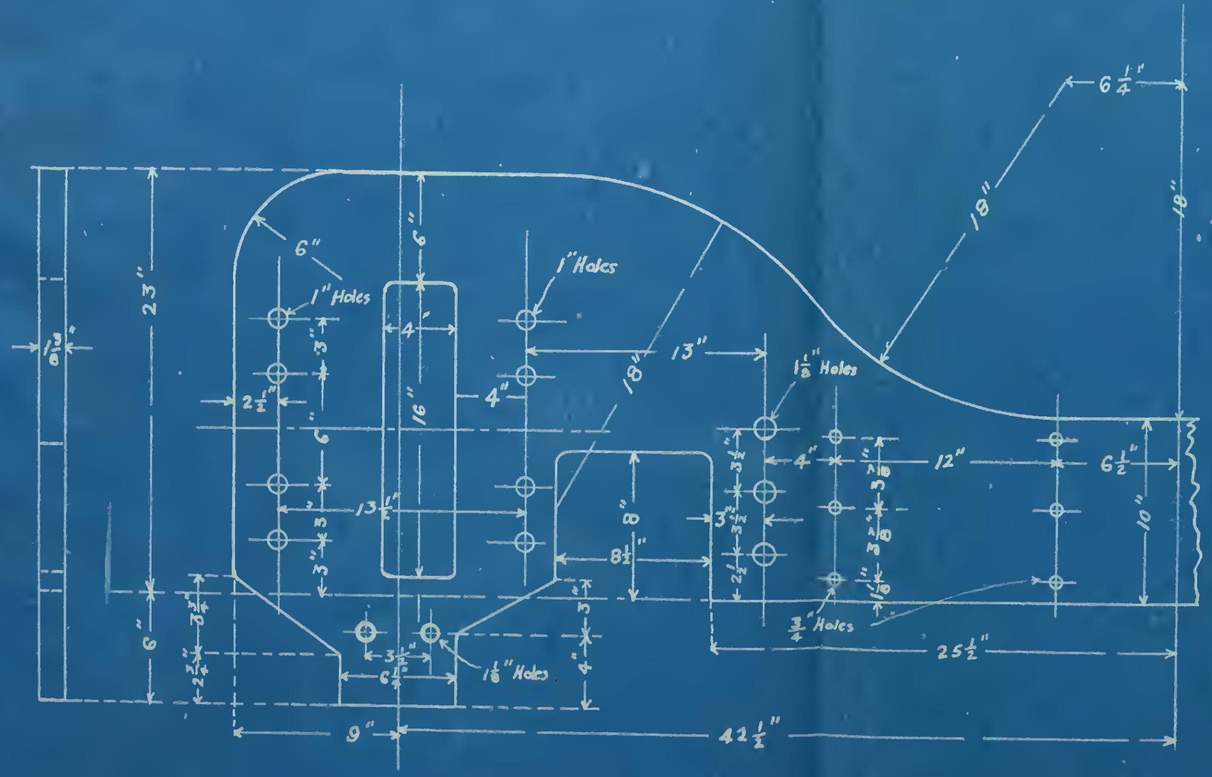
VALSCHAERT VALVE GEAR
FOR
SS R2 ENGINE OF C.B+Q.R.R.

Radius Rod and
Guide Yoke

Scale: 1" = 8"

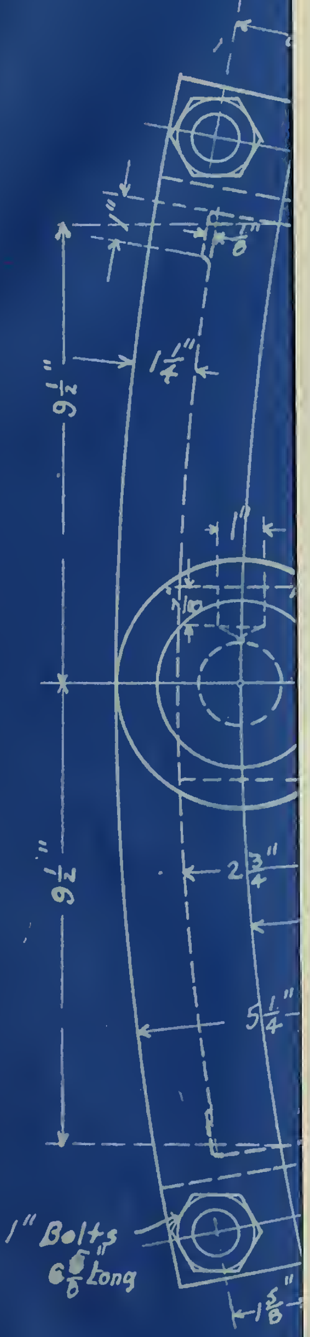
PLATE 5.





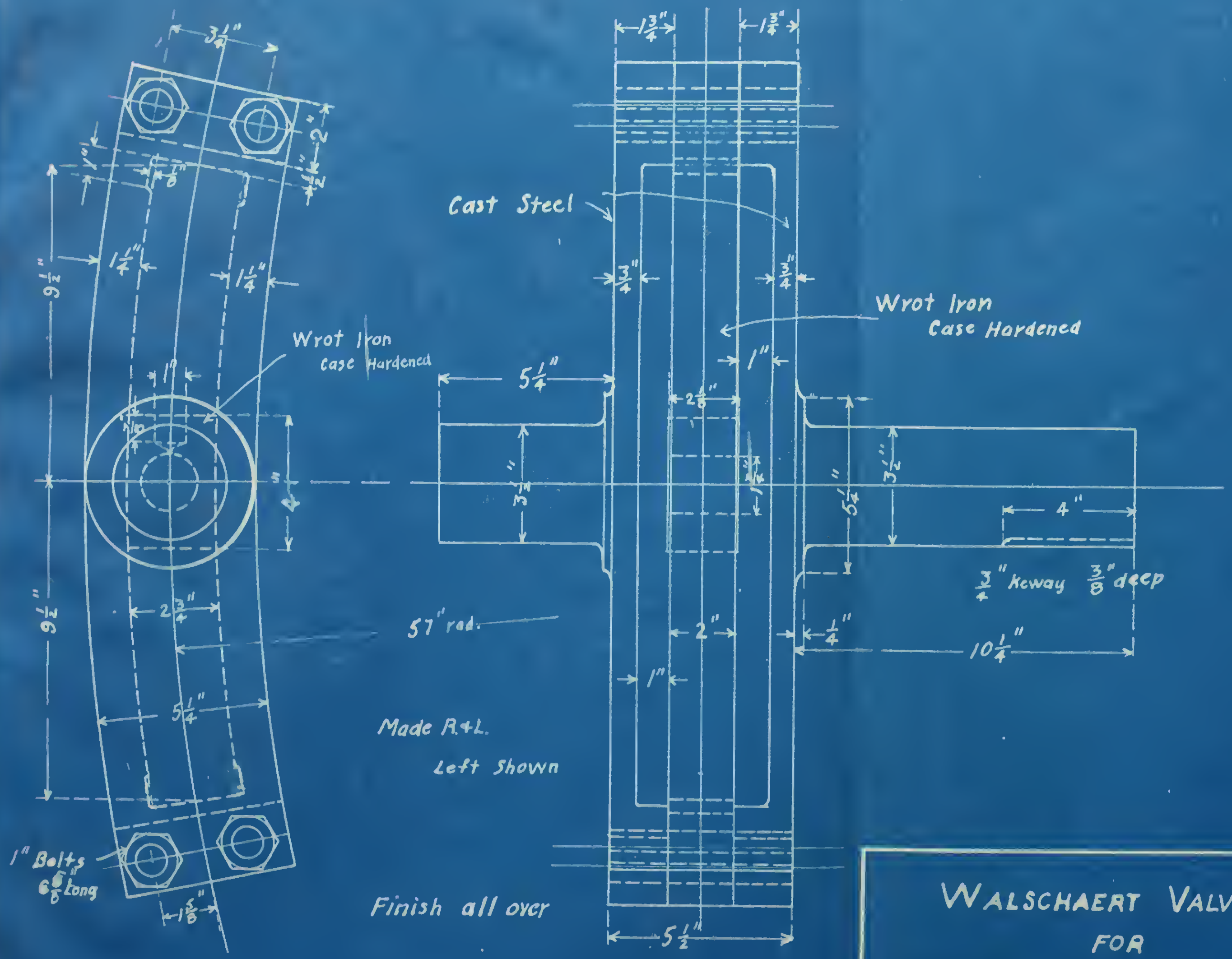
WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q.R.R.
Radius Rod and
Guide Yoke

Scale: 1"=8"



1"
1/8"
1¼"
9½"
1"
1/16
2¾"
9½"
5¼"
1" Bolts 6⅝" Long
1⅝"

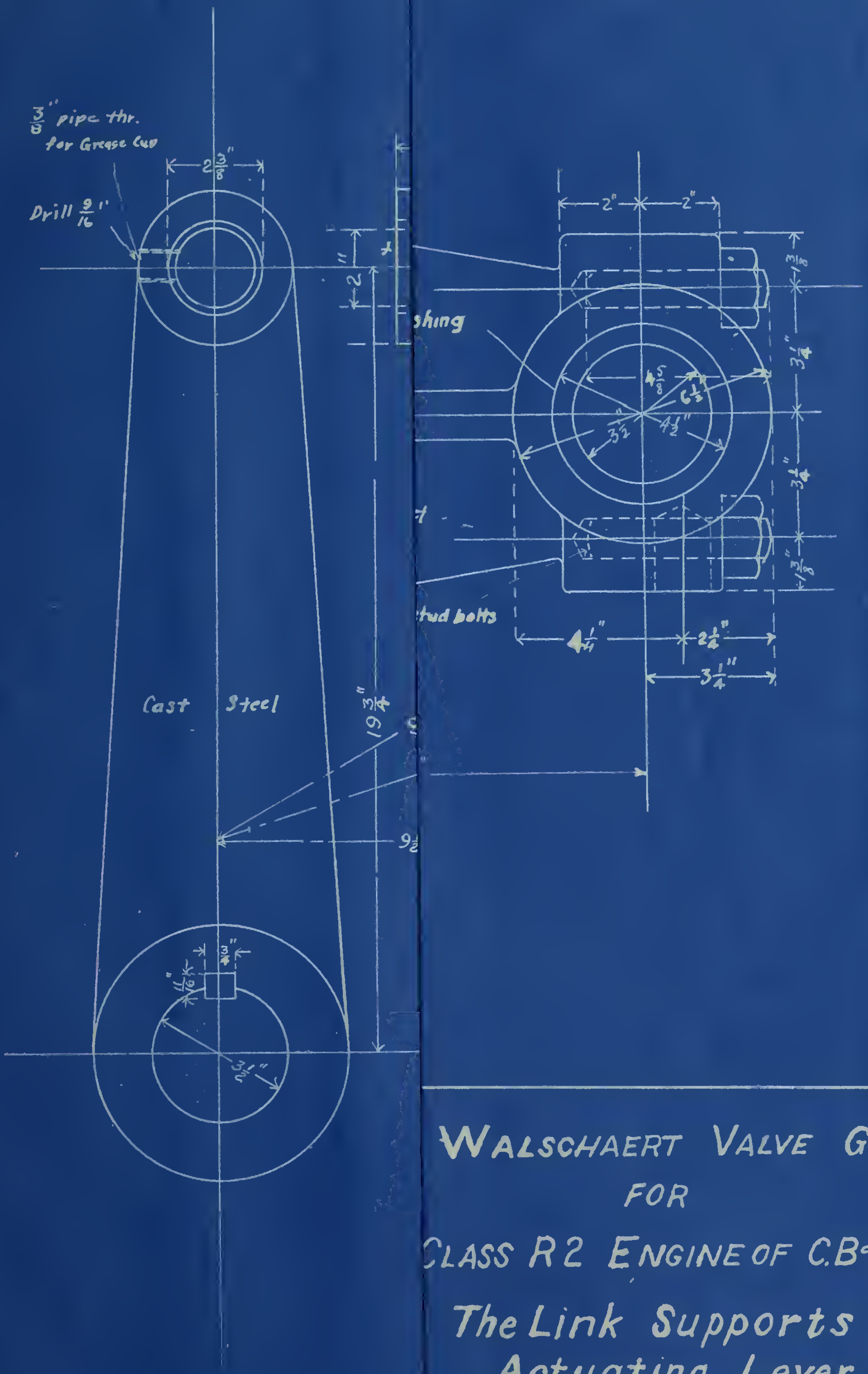
PLATE 6.



WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q. R.R.

The Link

Scale: 3"=1'

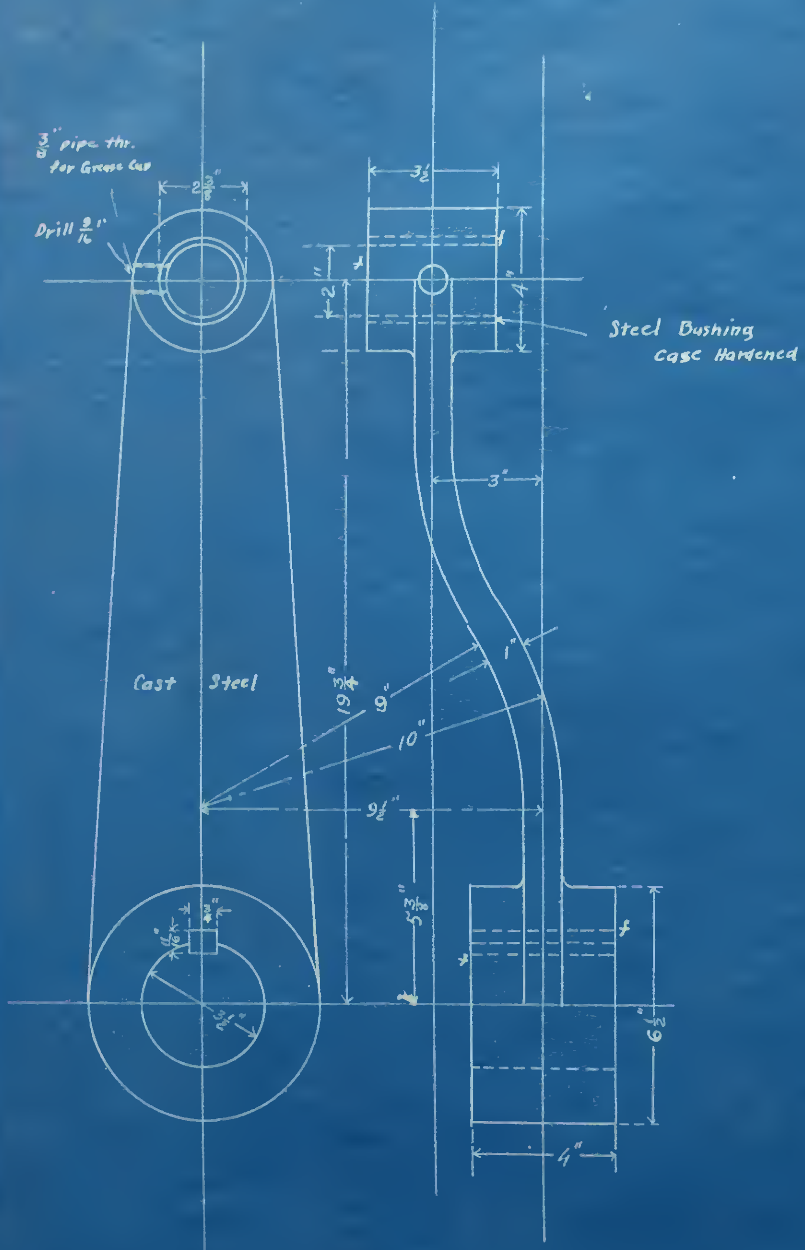


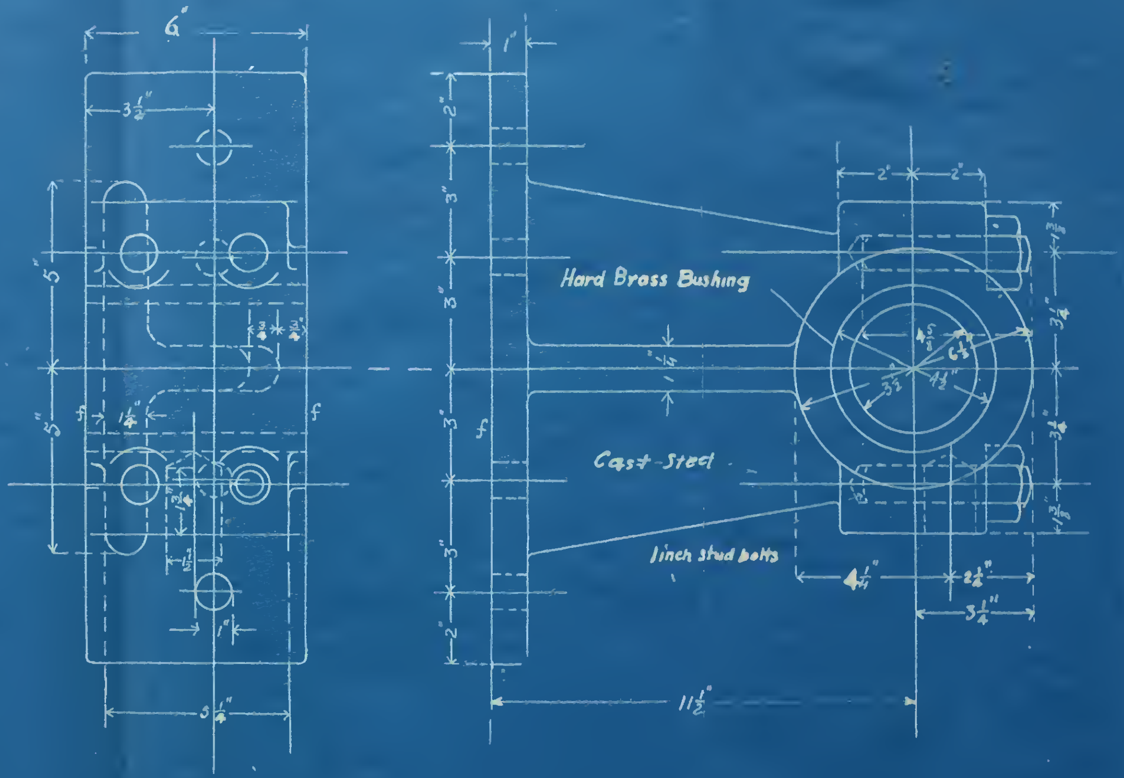
WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.& Q.R.R.

The Link Supports and Actuating Lever

Scale 3" = 1'

PLATE 7.

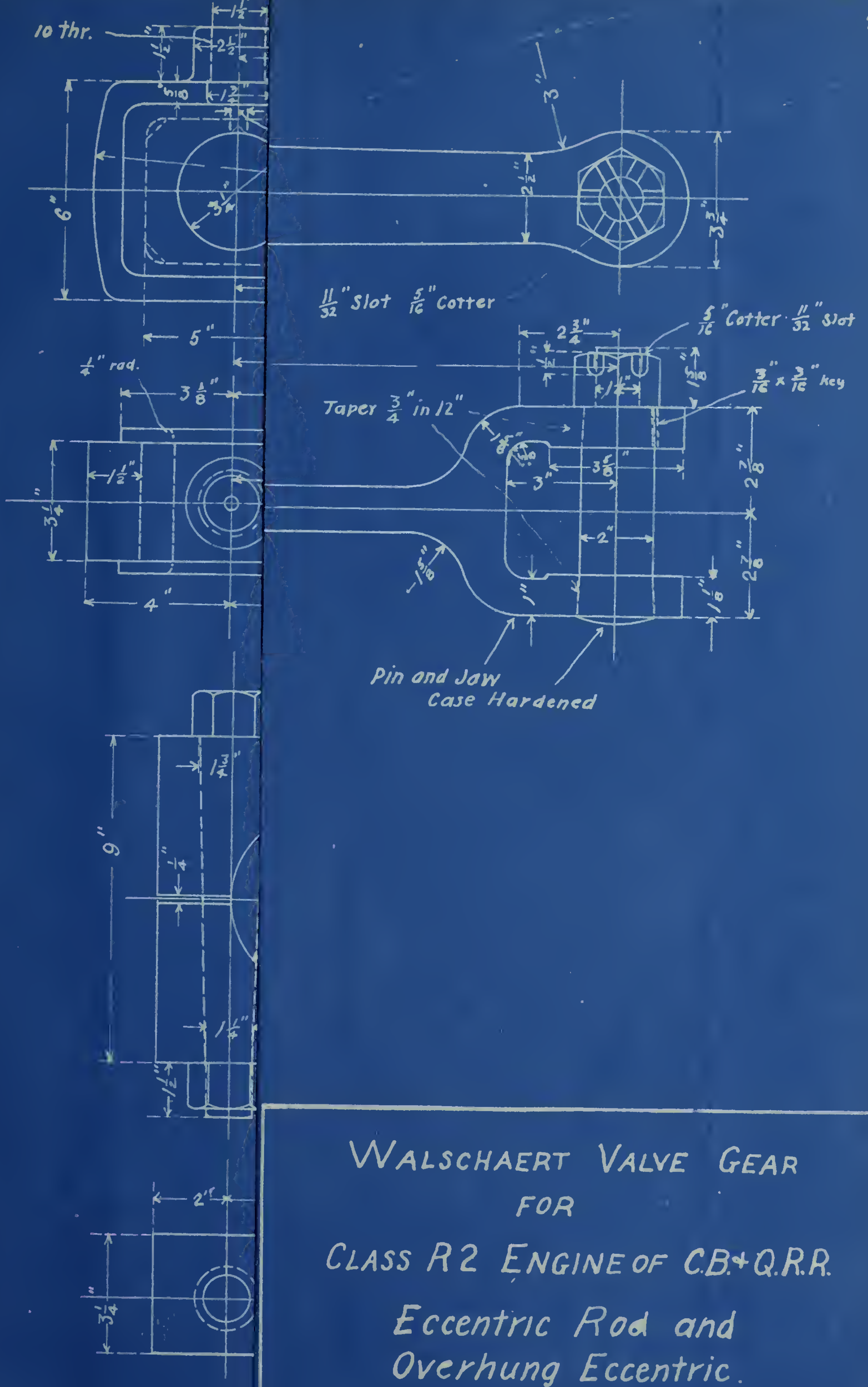




WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.& Q.R.R.

The Link Supports and
Actuating Lever

Scale 3" = 1'

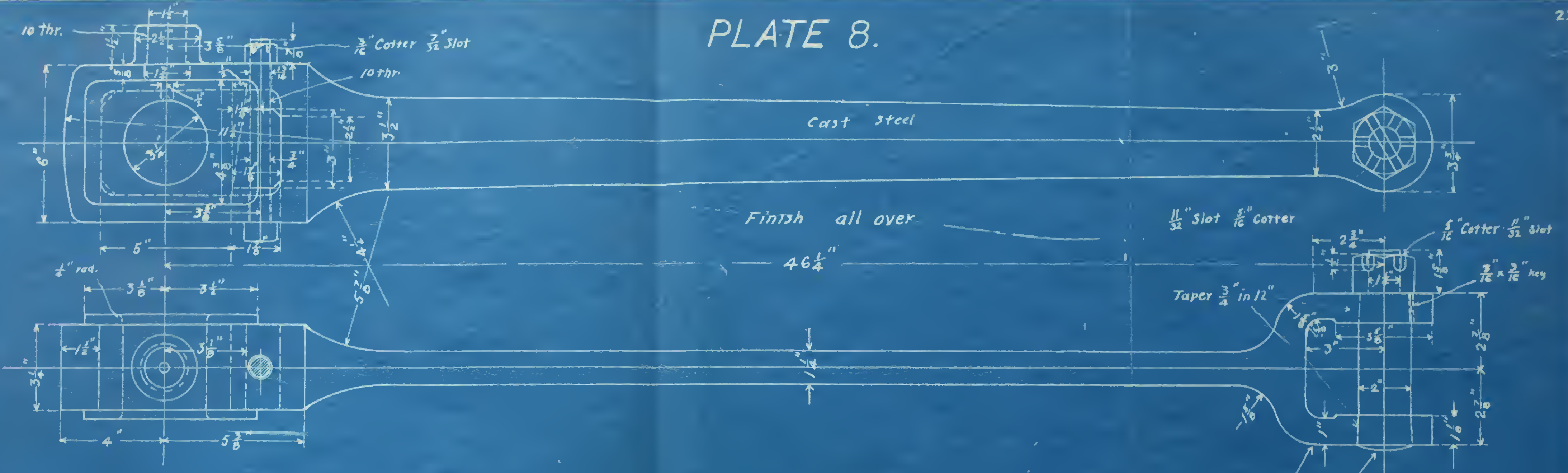


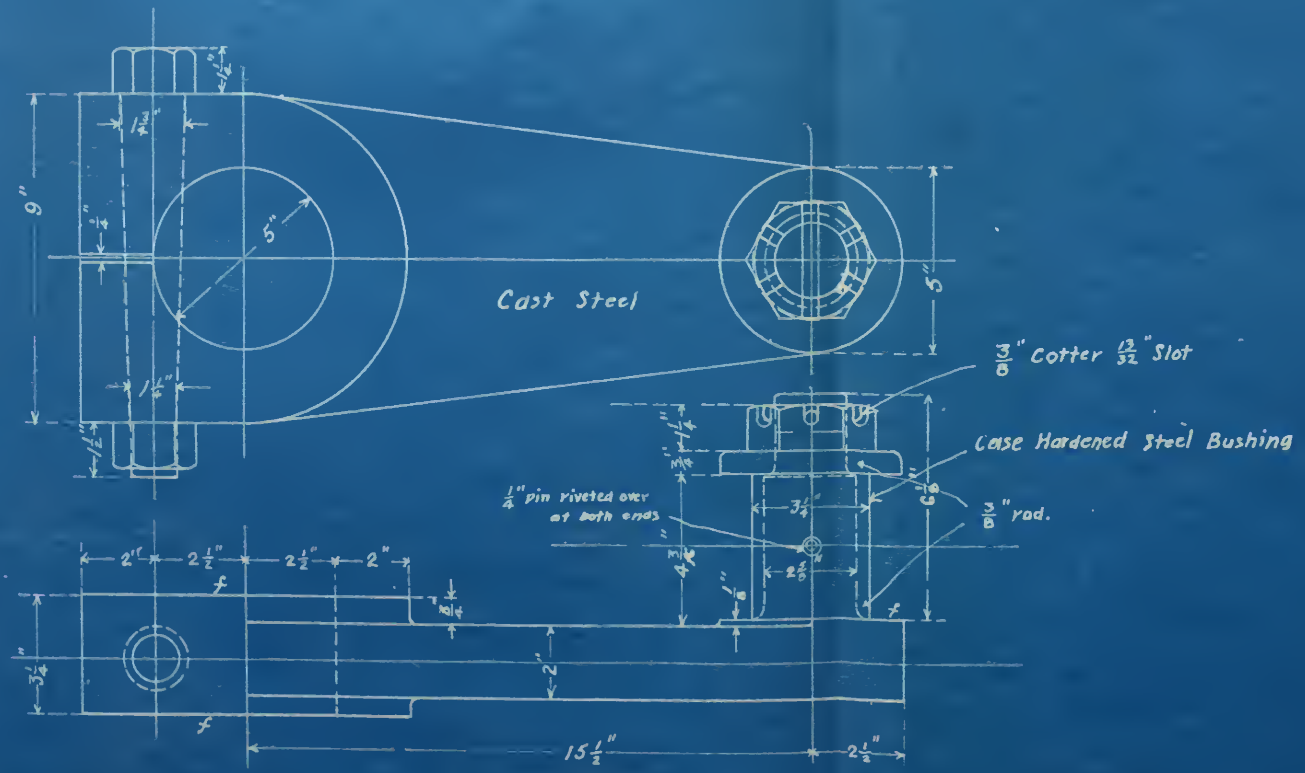
WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q.R.R.

Eccentric Rod and Overhung Eccentric.

Scale: 3" = 1'

PLATE 8.


10 thr.
$\frac{3}{16}$" Cotter $\frac{7}{32}$" Slot
10 thr.
Cast Steel
Finish all over
46$\frac{1}{4}$"
$\frac{1}{4}$" rad.
$\frac{11}{32}$" Slot $\frac{5}{16}$" Cotter
$\frac{5}{16}$" Cotter $\frac{11}{32}$" Slot
$\frac{3}{16}$" x $\frac{3}{16}$" key
Taper $\frac{3}{4}$" in 12"
6"
5"
4"
5$\frac{3}{8}$"
3$\frac{1}{2}$"
3$\frac{3}{4}$"
1$\frac{1}{4}$"
2$\frac{3}{4}$"
2$\frac{7}{8}$"
3"
2"



WALSCHAERT VALVE GEAR

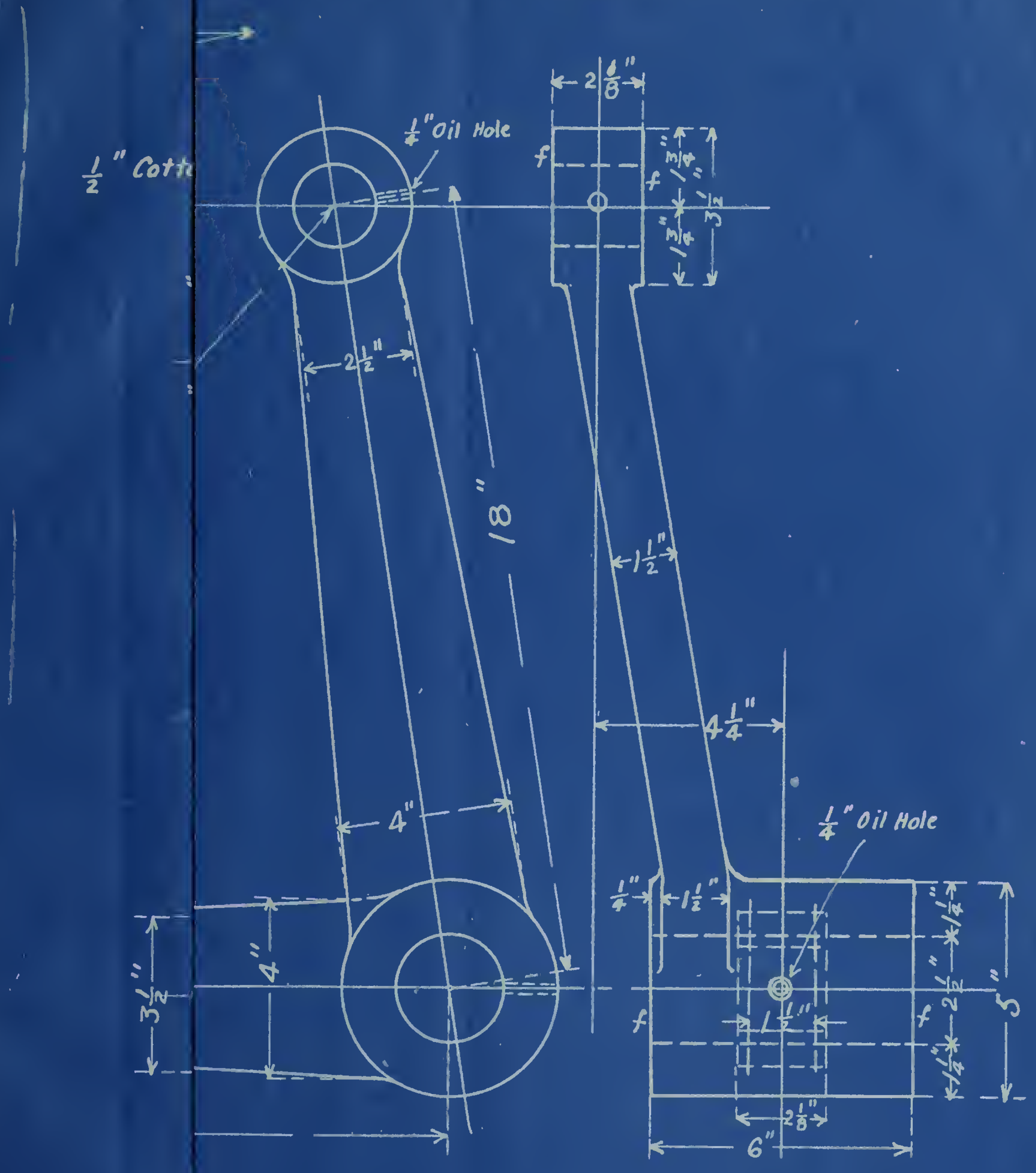
FOR

CLASS R2 ENGINE OF C.B.+Q.R.R.

Eccentric Rod and
Overhung Eccentric.

Scale: 3" = 1'

PLATE 9.

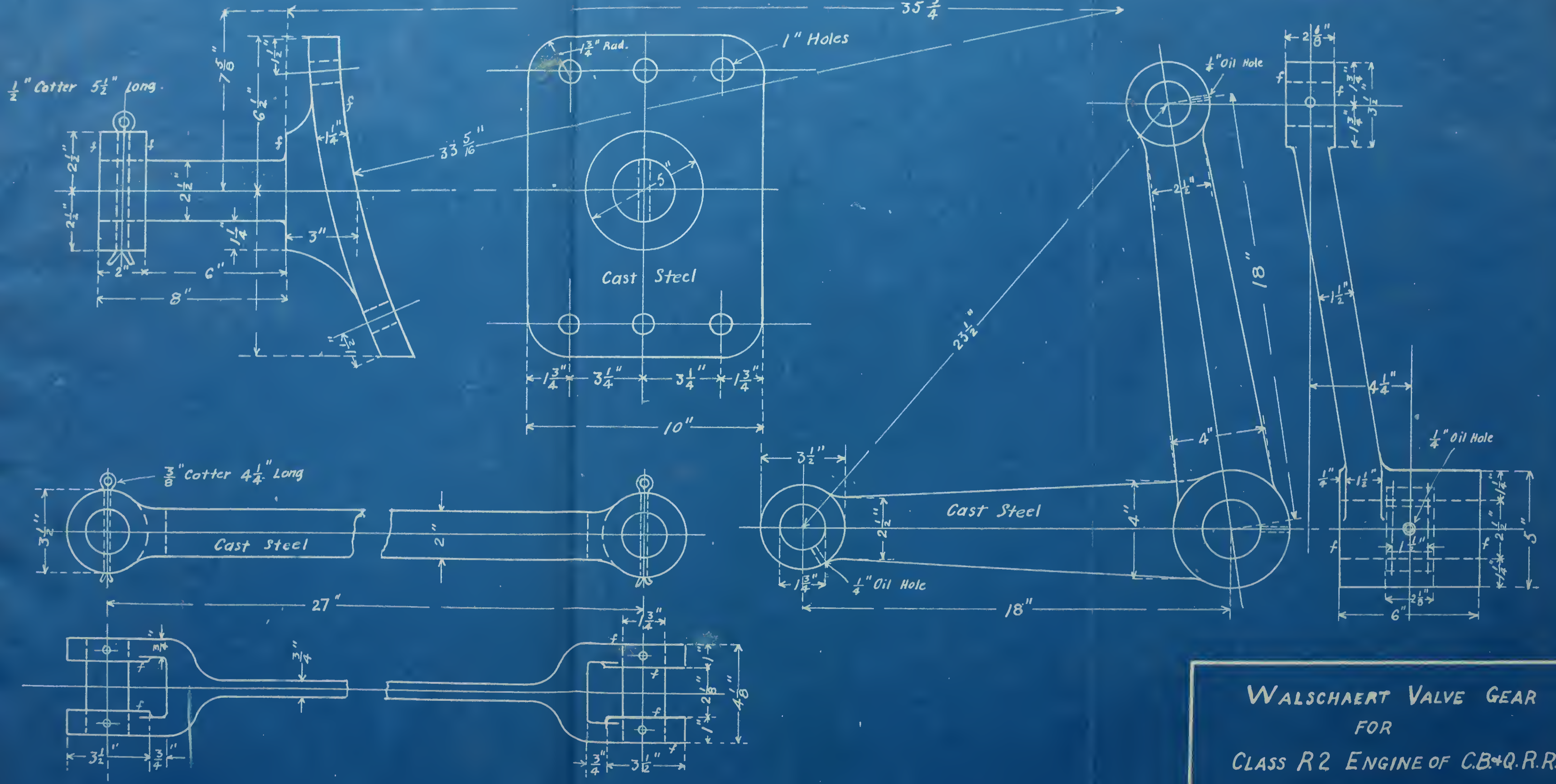


WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.&Q.R.R.

Radius Rod Hanger
and its Bell Crank

Scale: 3"=1'

PLATE 9.

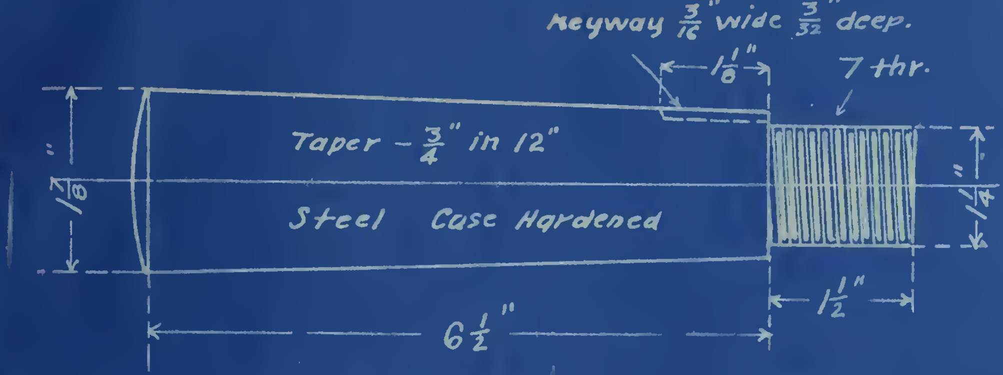


WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.&Q.R.R.

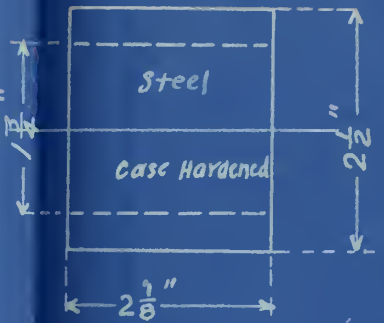
Radius Rod Hanger
and its Bell Crank

Scale: 3"=1'

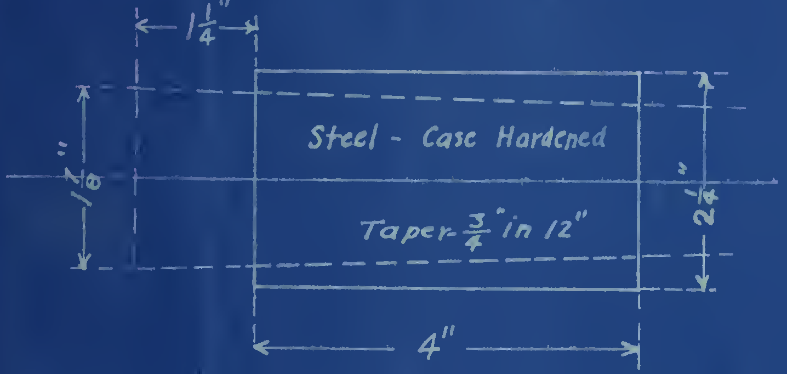
PLATE 10.



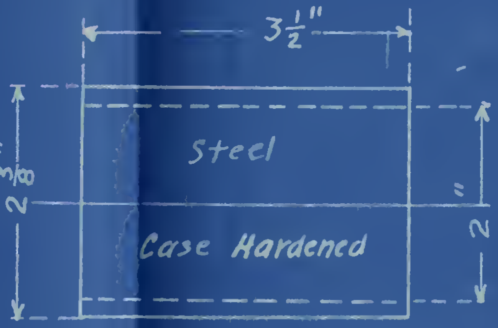
Combination Lever Pin. - 4 Required



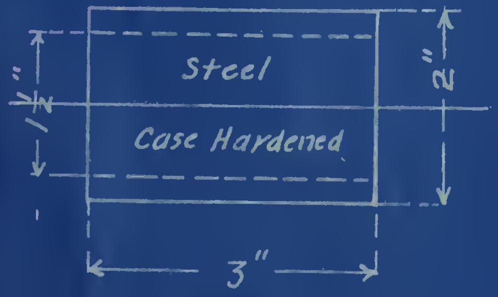
Rear Radius Rod Bushing
2 Required



Bushing for Front End of
Radius Rod and for Valve Guide.
4 Required



Link Lever Bushing
2 Required



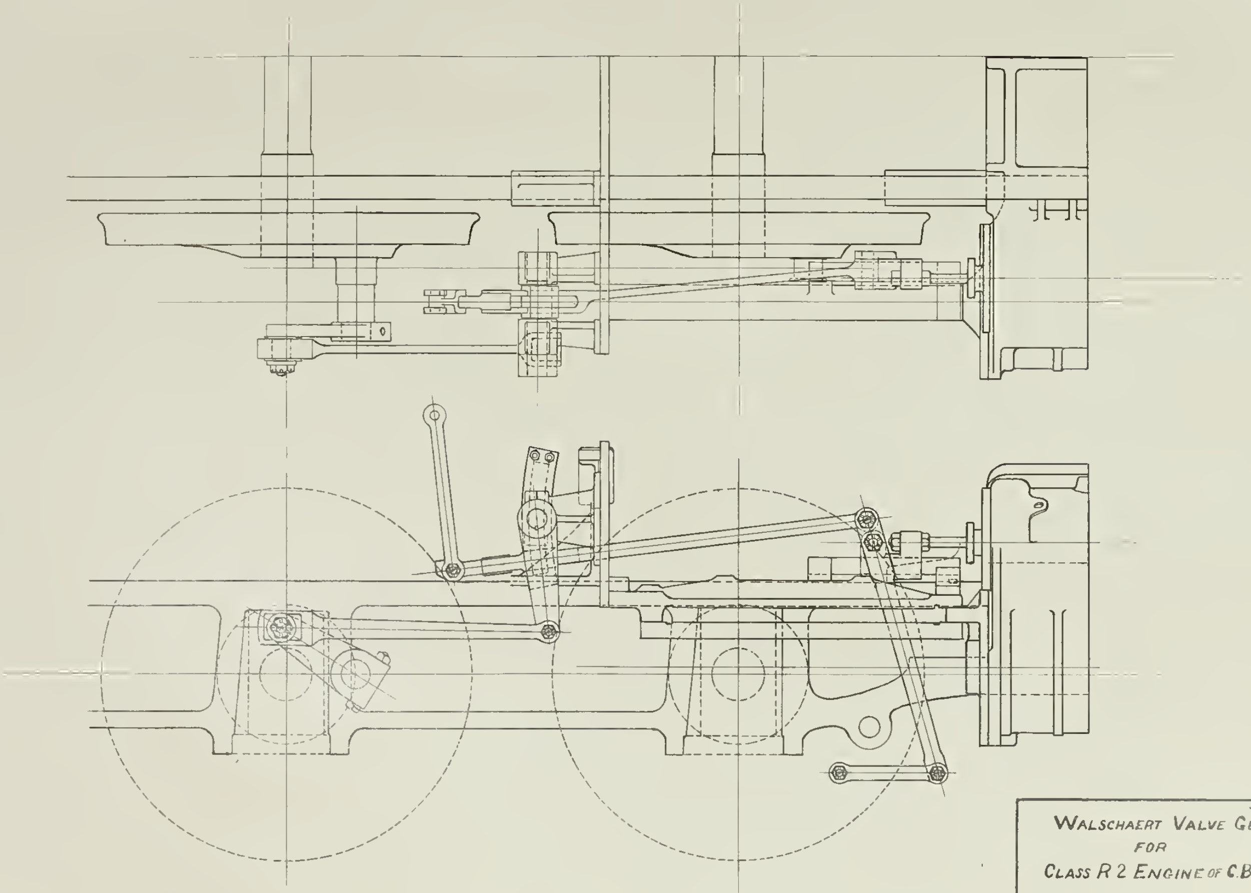
Bushing for Lower End of
Combination Lever
2 Required.

WALSCHAERT VALVE GEAR
FOR
CLASS R2 ENGINE OF C.B.+Q.R.R.

Miscellaneous Parts.

Scale: 6"=1'

PLATE 11.



WALSCHAERT VALVE GEAR
FOR
CLASS R 2 ENGINE OF C.B.&Q.R.R.
General Assembly
Drawing
Scale 1" = 1'

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